REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
November, 1994

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
Theater Missile Defense and Retaliation With Mixed Forces (RVs, Decoys, Bombers)

5. FUNDING NUMBERS
Privately Funded

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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Post Office Box 1674
Idaho Springs, CO 80452

8. PERFORMING ORGANIZATION REPORT NUMBER
R-114-NE

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Arms Control & Disarmament Agency
320 21st Street, N.W.
Washington, DC 20451

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
None

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified, Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Analysis of the relationship between a Russian theater missile defense system and second strike retaliation capabilities of the United States. The retaliatory roles of bombers, ballistic missile re-entry vehicles, and the decoys for RVs are considered.

14. SUBJECT TERMS
MORS, Retaliation, Decoys, Ballistic Missile Defenses, Discrimination

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Sta. 239-18
298-102

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THEATER MISSILE DEFENSE AND RETALIATION WITH MIXED FORCES (RVs, DECOYS, & BOMBERS)

F. S. Nyland

NOVEMBER, 1994

R-114-NE

Operational Research For Arms Control, Defense, And Public Policy

PREFACE

The purpose of this report is to provide analyses of the relationship between a Russian theater missile defense system and second strike retaliation capabilities of the United States. Since the details of such a defense system are not known at this time, an aggregated model of defenses is suggested. The retaliatory roles of bombers, ballistic missile re-entry vehicles (RVs), and the decoys which might accompany the RVs are the subject of this report.

This report should be of interest to the arms control community, defense officials, and others concerned with national security aspects of strategic and theater ballistic missile defenses.

None of the material contained in this report should be construed to represent the official views of the U.S. Arms Control and Disarmament Agency, the Department of Defense, or any other organization within the U.S. Government. The views are solely of those of the author.

CONTENTS

DECOYABM.MSS

I - INTRODUCTION

The U.S. Department of Defense is developing a theater high altitude area defense (THAAD) system. Its purpose is to defend U.S. forces deployed abroad, our friends and allies, from attacks by tactical ballistic missiles in potential conflicts in the third world. The Russians may want to build and deploy a similar system for the same general purposes. The aim of this report is to address the concerns about deployments of a theater missile defense (TMD) within the homeland of Russia to blunt a retaliatory strike. If Russia were to implement a first strike, the U.S. retaliation would be degraded by a Russian theater missile defense. The amount of this degradation would be a function of how extensive and how effective a Russian missile defense might be. To examine a worst case, it is assumed that a Russian missile defense might be very robust. The analyses contained in this report indicate that some of the degradation of a U.S. retaliatory strike caused by a missile defense might be alleviated through the use of decoys that accompany the ballistic missile re-entry vehicles that make up part of such a strike. U.S. bombers would also be a part of a retaliatory strike if they were on alert and provided with warning of an attack.

This report is organized to provide insights on a number of issues. First, the methods of analysis employed throughout the report are summarized. Following that, the assumptions made to examine first strikes and the retaliation are provided. These assumptions include the estimated forces and postures of both the U.S. and Russia under the terms of the START II Treaty. In addition, some estimates of U.S. forces surviving a Russian first strike are presented. The essence of the analysis is first viewed when the effectiveness of retaliatory strikes are estimated. The measure used in this analysis is the fraction of Russian valued assets that are damaged. Strikes will be examined where the U.S. retaliates without decoys, or with perfect decoys. Since many readers may feel that decoys may not be perfect, a further section of this report is devoted to analyzing retaliatory effectiveness with imperfect decoys. The analysis addresses discrimination between RVs and decoys, as well as some of the key parameters which may either cause decoys to be more or less effective. Since there are concerns about the first strike stability between the strategic forces and leadership of the U.S. and Russia, we will indicate the effects of missile defense, force posture, and decoys for ballistic missile RVs in this context. Finally we offer some observations and suggestions.

II - METHODS OF ANALYSIS

The methods of analyses employed in this report were designed to address a number of important issues related to preserving the the effectiveness of a retaliatory strike by the U.S. against Russia. These issues include: distribution of value amongst Russian targets, retaliation without and with decoys for ballistic missile re-entry vehicles (RVs), retaliation with forces consisting of both ballistic missiles and bombers, and the effect of varying degrees of defense discrimination between RVs and decoys.

Distribution of Value

The objective of a retaliatory strike is to damage the valued assets of Russia. The distribution of value amongst future aimpoints in Russia is not well known at this time. However, Bennett has made some estimates [1] that will be employed here. His analyses indicate that there would be approximately 2500 aimpoints in a future Russian target structure. An examination of his results indicate that the value of the targets could be approximated by a Pareto distribution with an exponent of about 0.5. In this analysis, we assume that the value at risk in a retaliatory strike would be:

1) $V = (WH/A)^{0.5}$

where WH is the number of warheads in the strike and A is the number of aimpoints (2500). Under this formulation, any arriving warhead is assumed to provide a satisfactory level of damage to the target or targets associated with each aimpoint.

Theater Missile Defense Effectiveness

If the Russians were to deploy a theater missile defense system in their homeland to blunt strategic nuclear retaliatory strikes, then the effectiveness of these defenses must be taken into account. At the present time, the exact nature of such defenses is unknown. To provide an estimate of defense effectiveness, we suggest that a first order model of defenses would be appropriate, such as a random subtractive defense. Under this defense, the probability of penetration of the defenses is given by:

2) $PRV = 1 - DP*(1-L)/(RV+D)$, when $RV+D > DP$

$= L$, when $RV+D <= DP$

where DP is the number of units of defense potential (the maximum number of RVs that can be engaged), L is the probability of leaking through the defenses before the defenses are exhausted,

RV is the number of RVs attacking, and D is the number of perfect decoys accompanying the RVs. The value at risk (VR) when missile defenses are present would acount for less than perfect penetration by including the probability of penetration stated in equation 2.

3) $VR = PRV*(RV/A)^{0.5}$

In an attack involving only ballistic missiles, the warheads would be the RVs arriving at the missile defense perimeter. The formulation up to this point was developed by Kent [2].

If the attack were carried out only by bombers, then PRV would be replaced by the probability of bombers penetrating air defenses (PBR), and W would be the number of bomber warheads in the attack. The value at risk in a bomber attack (VB) would be given by

4) $VB = PBR*(W/A)^{0.5}$.

In this analysis, we assume that PBR is constant and is specified by the analyst.

Generally, retaliatory attacks by the U.S. could be carried out by a mixed force of ballistic missiles and bombers, if some of the bomber force is put on strip alert. Under this assumption, two defense systems would need to be considered. Figure 1 illustrates this concept. In the figure, the fraction of value at risk is shown as a function of the number of warheads arriving at the defense perimeters (the solid CURVE). If ballistic missiles are assigned to the higher value aimpoints, then the value damaged by RVs would be given by equation 3. If the bombers were assigned to attack lower value targets, then the damage they would inflict would be given by a modified form of equation 4. Letting W represent the number of bomber warheads arriving at the air defense perimeter, the value damaged by the bombers would be

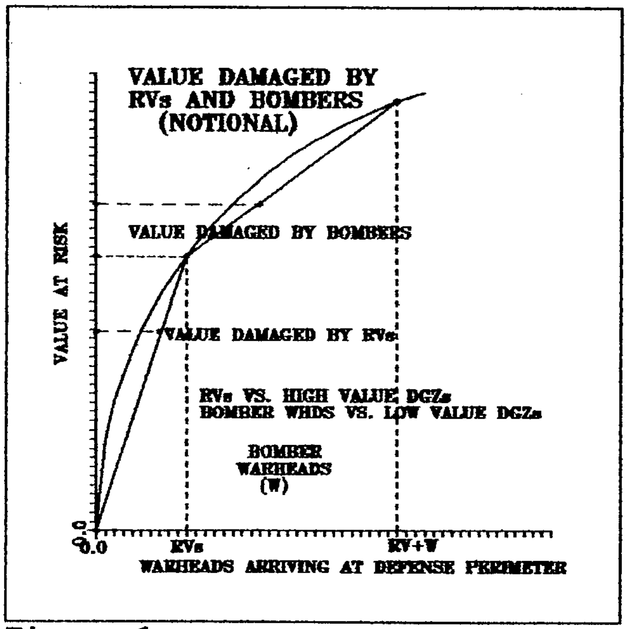

Figure 1

5) $VB = PBR*\{[(RV+W)/A]^{0.5} - [RV/A]^{0.5}\}$

and the total value damaged would be the sum of damage by RVs and damage by bomber warheads, VR+VB.

The total value damaged by both bombers and ballistic missiles can be maximized through appropriate allocation of the different types of weapons. It can be shown that bomber weapons should be sent against the higher value aimpoints if PBR>=PRV. Conversely, RVs should be sent against the higher value aimpoints if the probability of RV penetration of missile defenses is greater than the probability of bombers penetrating air defenses, i.e. PRV>PBR. In the remainder of this analysis, we assume that the value damaged in a retaliation follows this allocation rule.

The above analysis method can be used to evaluate the effectiveness of retaliatory or other types of strikes, with or without decoys. If the analyst wishes to consider more detail concerning defenses against bombers, then it would be appropriate to insert a more detailed function describing bomber penetration.

Kent, in his analysis of defenses [2], concluded that the random subtractive defense mode provided the best estimator of defense effectiveness currently available. To enforce this conclusion, it was necessary for the retaliator to allocate his RVs and decoys in a special way. One RV was aimed at each aimpoint until all available RVs had been assigned to am aimpoint. Then, each RV was accompanied by enough decoys so that no matter how the defense allocated its firepower, the value saved by each defense potential unit was the same. Under these conditions the difference in effectiveness between a random subtractive defense and an adaptive preferential defense was small. In Kent's analysis of a scaled down attack (25 RVs, 25 decoys, 40 aimpoints, and 17 defense interceptors), the random subtractive defense mode was about 5% less effective than the adaptive preferential defense mode in terms of value damaged. This small advantage could vanish if the defender were to make any allocation or discrimination errors. For larger scale attacks examined by the author (986 RVs, 1972 decoys, 2500 aimpoints, and a defense potential ranging between 600 to 1000 units), the same trends hold. The differences in attack outcomes vary less than 5%. Based on these comparisons, the estimator of defense effectiveness used in the analyses to follow will be based on the assumption of a random subtractive defense mode of operation.

<u>Decoy Credibility and Discrimination</u>

What if the defense has some capability to discriminate between RVs and decoys? The purpose of this discussion is to introduce a method of analyzing this problem based on work performed in the late 1960's by S. Layno [3].

When a defender is faced with two types of objects which may be somewhat similar, he can segregate them based on his perceptions. Two probabilities are the basis for his perceptions: the probability that an RV is perceived as a decoy (f), and the probability that a decoy is perceived as an RV (g). The number of perceived RVs (r) would be given by

$$(6) \quad r = (1-f)*RV + g*D,$$

and the number of perceived decoys (d) would be given by

$$(7) \quad d = (1-g)*D + f*RV$$

where RV is the actual number of RVs, and D is the actual number of decoys.

The probability of survival of the RVs in face of the defense is given by

$$(8) \quad PRV = (1-f)*L^{(IRV/r)} + f*L^{[(DP-IRV)/d]}$$

where L is the defense leakage (or one minus the probability of kill by one unit of defense potential), IRV is the number of units of defense potential allocated to fire at perceived RVs, and DP is the total number of defense potential units available. If the defense allocates his firepower properly, he can minimize the probability of survival of the RVs. Differentiating PRV with respect to the defense potential allocated to perceived RVs (IRV) and setting the result equal to zero, the allocation is given by

$$\begin{aligned}(9) \quad IRV &= DP*r/(r+d)*\{1+d/DP*\log[r/d*f/(1-f)]/\log(L)\} \\ &\qquad \text{where } f+g<1 \\ &= DP*r/(r+d) \\ &\qquad \text{where } f+g>=1\end{aligned}$$

which is a uniform allocation of interceptors to perceived RVs but modified by a hedging factor involving defense potential, perceived objects, and defense leakage. For small defense inventories and low values of f and g, all interceptors will be aimed at perceived RVs. If the sum of the two probabilities f and g is equal to or greater than one, then the defender is totally confused and allocates his fire evenly across all objects, provided that he is aware of the degree of his own confusion. In between these extremes, the defender may allocate his firepower to perceived decoys on the chance that they really are RVs. This allocation usually occurs when the defender has a large defense potential compared to the number of perceived RVs. To obtain an estimate of RV penetration, the number of defense potential units allocated to perceived RVs given by equation 9 is then substituted into equation 8.

This formulation permits the analyst to select a threshhold where two probability distributions (one for decoys, and one for RVs) overlap. The author often sets f=g and labels this value as a "confusion factor." The analyst need not set the two probabilities equal. If the means and standard deviations of the distributions are known, then the defender may bias his threshhold to lessen the number of surviving RVs. Setting threshholds for discrimination will be addressed later.

III - ASSUMPTIONS

The purpose of this chapter is to outline the basic assumptions to be used in these analyses. These assumptions include the composition of forces and their postures, and defense parameters.

Forces and Postures

The composition of strategic nuclear forces examined in this report are based on the assumption that the START II Treaty is in force. The force compositions are those suggested by the author and should not be construed as official views of any government agency. The assumed forces do meet the constraints of the START II Treaty, e.g., no land based ballistic missiles with multiple independently-targeted re-entry vehicles (no MIRVs), fewer than 1750 warheads on sea launched ballistic missiles (SLBMs), and a total inventory of nuclear warheads of about 3500 for both sides.

The strategic nuclear forces of the United States consist of land based intercontinental ballistic missiles (ICBMs), sea launched ballistic missiles (SLBMs), and bombers. Currently, SLBMs are carried on 18 submarines (SSBNs). Table 1 indicates the assumed force mix. Force postures are also indicated. Posture A represents the current situation as directed by President Bush: no bombers would be on day-to-day strip alert. Posture B represents a condition where about 30% of the bombers would be on strip alert.

TABLE 1 - U.S. STRATEGIC NUCLEAR FORCES

System	Warheads	Alert or At-Sea Rate (%)	
		Posture A	Posture B
500 Minuteman ICBM	500	100	100
432 SLBM (18 SSBN)	1728	66.7	66.7
52 B-52 bombers	952	0	30
20 B-2 bombers	320	0	30
Total warheads	3500		

In examining retaliatory strikes, the U.S. forces surviving a Russian first strike must be specified. For purposes of this analysis, we assume that bombers not on alert are destroyed, and SLBMs in port are destroyed. With regard to the Minuteman

missiles, we assume that the Russians would aim two warheads (single shot probability of damage of 0.6) at each silo. The results of these assumed attack characteristics are summarized in Table 2.

TABLE 2 - U.S. Forces Surviving a First Strike

System	Warheads Surviving a First Strike Posture A	Posture B
Minuteman ICBM	80	80
Trident SSBN	1152	1152
Bombers (B-52 & B-2)	0	384
Total warheads	1232	1616

Some further assumptions are needed to examine the effectiveness of ballistic missile and air defenses. For the ballistic missiles, it is assumed that the product of their probabilities of availability and reliability is 0.8. From this assumption, we note that 986 RVs will arrive at the perimeter of a theater missile defense system if one is deployed in Russia. With regard to the bombers, we assume that the product of their probabilities of reliability and escape is 0.9, and their probability of penetrating Russian air defenses is 0.9. Thus, about 311 bomber warheads are expected to arrive at their aimpoints.

Later in this report, the first strike stability between U.S. and Russian forces will be examined. To perform this analysis, Russian strategic nuclear forces need to be specified. Table 3 summarizes our assumptions concerning Russian forces and their postures.

TABLE 3 - Russian Strategic Nuclear Forces & Postures

System	Warheads	Alert or At-Sea Rate (%) Posture A	Posture B
193 ICBMs in silos	193	100	100
279 Mobile ICBMs	279	0	20
120 SLBM (Typhoon)	1200	33	33
112 SLBM (Delta)	448	29	29
75 Bear-H bombers	1200	0	31
15 Blackjack bombers	180	0	33
Total warheads	3500		

For both sides, there are other common assumptions. It is assumed that no ICBMs will be launched on warning or under attack (no "prompt" launch). If either side launches a first strike, about 80% of the total warheads will be used. The assumed probabilities of single shot damage to various targets are as follows: against a silo, 0.6; against an SSBN in port, 0.7; against a mobile ICBM garrison with non-alert missiles, 0.8;

against an airbase with non-alert aircraft, 0.8. For both sides, aimpoint value is assumed to follow the Pareto distribution with an exponent value of 0.5. The number of aimpoints in Russia is assumed to be 2500. For the U.S., the number of aimpoints is assumed to be 1600.

IV - RETALIATION WITH OR WITHOUT PERFECT DECOYS

The purpose of this chapter is to examine the effectiveness of retaliatory attacks without decoys and with perfect decoys. Since the extent of theater missile defenses to be deployed in Russia is not known at the present time, we will vary the defense potential between zero and 1000 units. The effectiveness of a retaliatory strike by the U.S. in this report is estimated by examining the fraction of Russian valued assets damaged. The value damaged will be a function of the level of the theater missile defenses.

Retaliation Effectiveness Without Decoys for RVs

The first step in setting the framework for the analysis is to examine the effect of various leakage rates. Figure 2 shows the probability of RV penetration as a function of the ratio of RVs to defense potential. When the number of RVs is less than the defense potential, then the probability of penetration of the defenses is set by the leakage rate. When the number of RVs exceeds the defense potential, then the probability of penetration increases, since the first RVs leak through, but subsequent RVs penetrate unopposed after the defense resources have been depleted. Various leakage rates are indicated. For this analysis, we assume a robust theater missile defense with a leakage of 0.1.

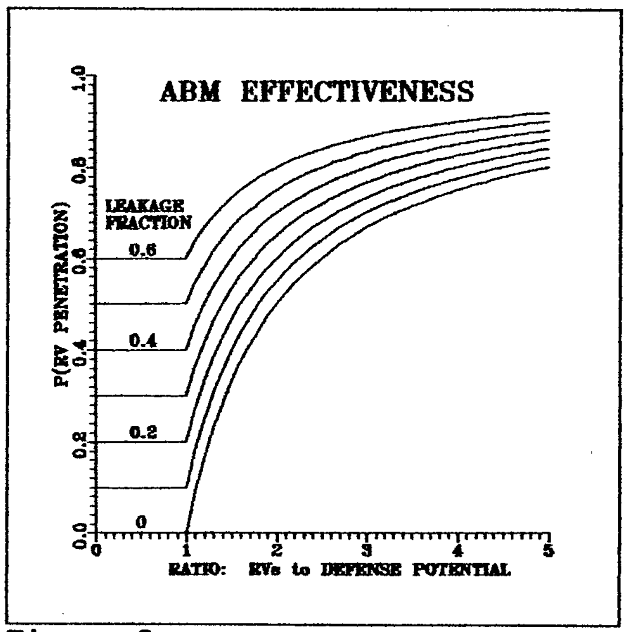

Figure 2

The next step in this analysis will be to estimate the number of U.S. RVs penetrating to their aimpoints when no decoys are employed. Figure 3 shows the results. Without missile defenses, all 986 RVs arriving would penetrate. As the level of defenses increases fewer and fewer RVs arrive at their targets as indicated by the lower line in figure 3 (no bombers in the retaliatory strike, posture A). If the retaliation consists of both ballistic missiles and bombers (posture B), then the value damaged in the strike is indicated by the upper line. The bombers are not countered by the missile defenses, but do have to contend with air defenses. In this analysis, it is assumed that alert bombers successfully escape from their bases with a probability of 0.9. The probability of penetration of air defenses is assumed to be 0.9. The change in slope of the upper line is caused by a switch in allocation of weapon types. When the deployment of missile defenses is low (less than about 100 units of defense potential), SLBMs and ICBMs are assigned to attack the most valuable aimpoints in Russia. If the level of missile defenses is greater than about 100 units of defense potential, then the bombers are assigned to attack the most valuable aimpoints. For larger deployments of missile defenses, the probability of bomber defense penetration is higher than that of the SLBMs and ICBMs, and the bomber warheads are able to incrementally damage more value than ballistic missile RVs. Overall, ballistic missile defenses deployed in Russia would have a deleterious effect on a U.S. retaliation if some sort of corrective actions were not taken.

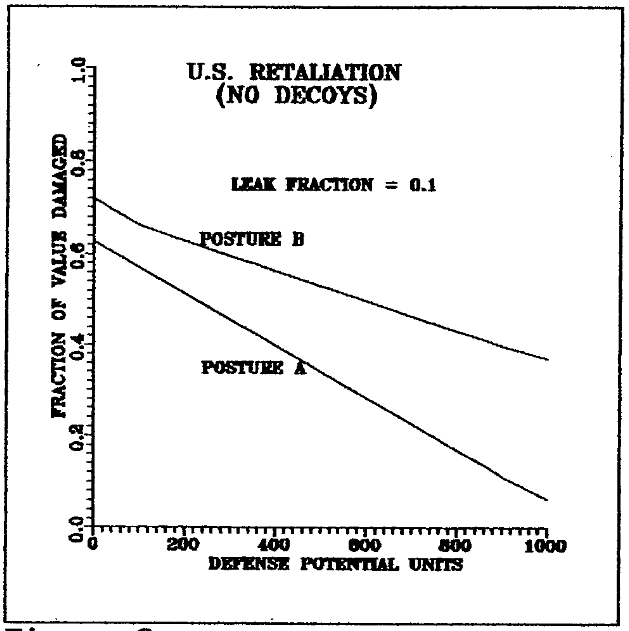

Figure 3

A number of actions that might offset the effects of a Russian missile defense deployment are available to U.S. planners. One action would be to increase the at-sea rate of strategic submarines. Another action would be to increase the number of bombers on strip alert. Each action will be examined by estimating the number of warheads needed to enforce a desired fraction of value damaged.

Under the START II Treaty limits and assuming that 2/3 of the strategic submarines would be at sea on a day-to-day basis, there would be 1152 SLBM RVs surviving a first strike. The

effects of a Russian deployment of a robust missile defense in their homeland might be offset by increasing the number of SLBM RVs at sea under day-to-day conditions. Figure 4 indicates the number of SLBM RVs that would need to be launched to provide various levels of damage to valued assets in Russia as a function of the level of missile defense deployments. The base case when there are no missile defenses present is a damage level of 0.72 when 2/3 of the SLBMs are at sea, and 30% of the bombers are on strip alert. The dashed line slightly above a damage level of 0.7 indicates how many SLBM RVs must be at sea to maintain this base case damage level. If the Russians were to deploy about 300 units of defense potential, then <u>all</u> of the SLBMs would have to be deployed at sea as indicated by the horizontal line labeled "inventory." For deployments of missile defenses greater than 300 units of defense potential, the U.S. would have to plan on achieving lower levels of damage in a retaliatory strike.

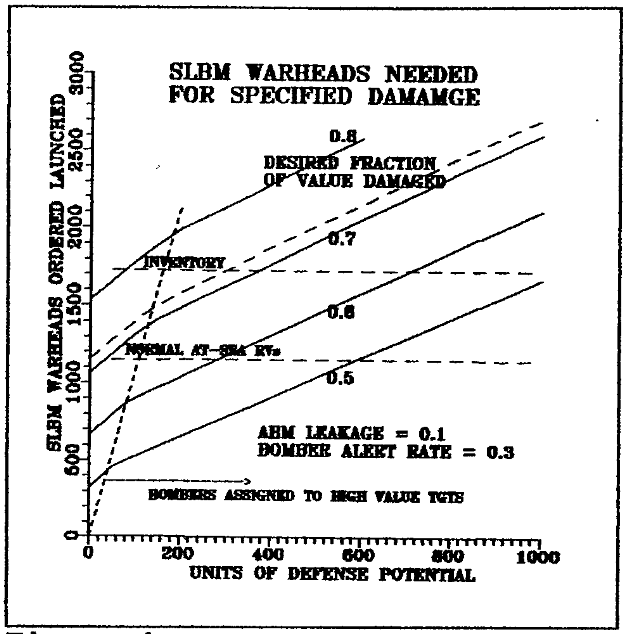

Figure 4

The change in allocation between ballistic missile and bomber warheads is also indicated as a function of missile defense deployments. The lower slope of the curves as missile defense potential is increased is caused by sending the bombers against the higher value targets.

Bomber alert rates could be increased in an attempt to correct for Russian deployments of missile defenses. Present U.S. policy set by former President Bush is that there will be no bombers on strip alert. Previously, the bomber alert rate was about 30%, and we assume that this alert rate would be needed if the Russians began to deploy a theater missile defense within their homeland. Thus, in this analysis, the base case bomber alert rate will be 30% (or 384 warheads), and would include both B-52 and B-2 bomber types. If U.S. planners desired to maintain a constant damage level in the presence of Russian missile defenses, then the alert rate of the bombers would have to be increased beyond 30%. In the analysis to follow, it is assumed that the at-sea rate of the SLBMs would be fixed at 1152 RVs (2/3 of the total inventory).

Figure 5 shows the number of bomber warheads that would have to be ordered to launch as a function of the Russian defense potential to maintain various desired value damaged. The change in slope in the curves at about 100 units of defense potential results from the change in allocation of weapon types discussed earlier. When there are no missile defenses to blunt a retaliatory attack, 384 bomber weapons would be ordered to launch. In combination with the SLBM and ICBM RVs, the total damage to Russian value would be 0.72. To maintain this basic level of damage (the dashed curve), more and more bomber warheads would need to be put on strip alert. If the defense potential were to be increase to about 650 units, then all of the bombers would need to be put on strip alert. Alternatively, planners could accept values of damage somewhere between 0.5 and 0.7 and partially ameliorate the effect of Russian ballistic missile defenses.

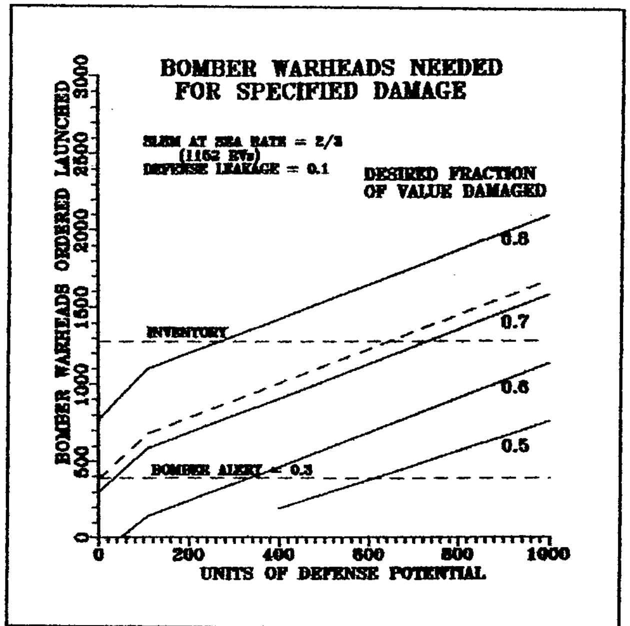

Figure 5

Overall, these analyses indicate that planners could offset partially the loss of effectiveness of a Russian deployment of robust missile defenses by either 1) increasing the number of SLBMs at sea, or 2) increasing the strip alert rate of bombers. Neither of these steps alone could completely offset the effect of increased ballistic missile defenses if the defense potential were greater than 600 units. Some relief might be afforded if the robustness of missile defenses were not so great, i.e., if the leakage rate were larger than that assumed here. Another relief might be afforded if some form of penetration aids were used in conjunction with U.S. ballistic missile RVs, such as decoys.

Retaliation Effectiveness With Perfect Decoys for RVs

The employment of perfect decoys could increase the probability of RV penetration of missile defenses, at least in terms of the formulation used in this report. To examine this alternative, it is assumed that the ratio of decoys to RVs would be 2.0. Under this assumption, the missile defenses would be faced with three times the number of credible penetrating objects, and defensive firepower would be overwhelmed even when the defense potential approached 1000 units. For the case where

leakage is 0.1, the defense potential is 1000 units, and 984 RVs and 1972 decoys arrive at the defense perimeter, the probability that RVs would penetrate the defenses would be about 0.7. Without decoys, the RV penetration probability would be much lower, less than 0.1. Because of this trend, the effects of ballistic missile defenses might be more nearly offset if the retaliation consisted, in part, by ballistic missile RVs accompanied by decoys. In this discussion, we assume that the decoys are perfect to establish an upper bound on the effectiveness of the retaliation as measured in terms of the fraction of damage to valued assets in Russia. Later, the effects of imperfect decoys and discrimination will be considered.

What would be the effectiveness of the retaliation when RVs are accompanied by decoys compared to the results noted earlier? Figure 6 shows the comparison. The dashed lines show the results of the analysis without decoys, and the solid lines indicate outcomes when perfect decoys are used to reduce the effectiveness of missile defenses. The ratio of decoys to RVs is two. For the case where there are no defenses, the two cases are the same for both postures A and B. As the level of missile defenses increases, the differences become larger. At higher levels of missile defenses, the degradation in retaliatory effectiveness is much less if decoys are employed. Although the change in slope in the uppermost curve is difficult to detect in the figure, the numerics indicate that bombers would be assigned to the higher value aimpoints if the defense potential is greater than about 330 units. For higher values of defense potential, the probability of bomber penetration is higher than RV penetration. When there were no decoys (the upper dashed line), the switch point ocurred when the defense potential was about 110 units.

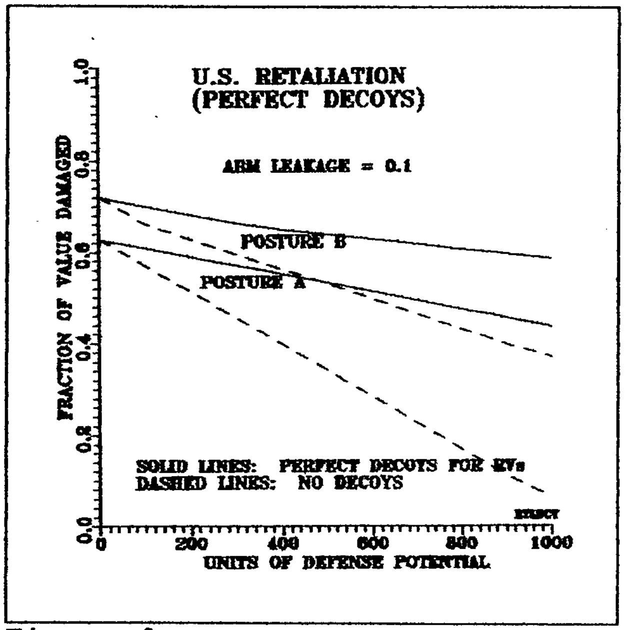

Figure 6

The purpose of the following analyses will be to indicate how many weapons, either SLBM RVs or bomber warheads, would be needed to maintain various levels of damage in a retaliatory strike. The results will be presented in the same form as shown earlier (Figure 4 and Figure 5), but with the inclusion of perfect decoys for ballistic missile RVs.

The results of these two analysis are shown here. Figure 7 indicates the number of SLBM RVs that must be ordered to launch to maintain various levels of damage. Figure 8 indicates the number of bomber warheads that must be ordered to launch to maintain various levels of damage. As in the previous analyses, the fraction of value damaged when both bombers and RVs were used to retaliate is about 0.72.

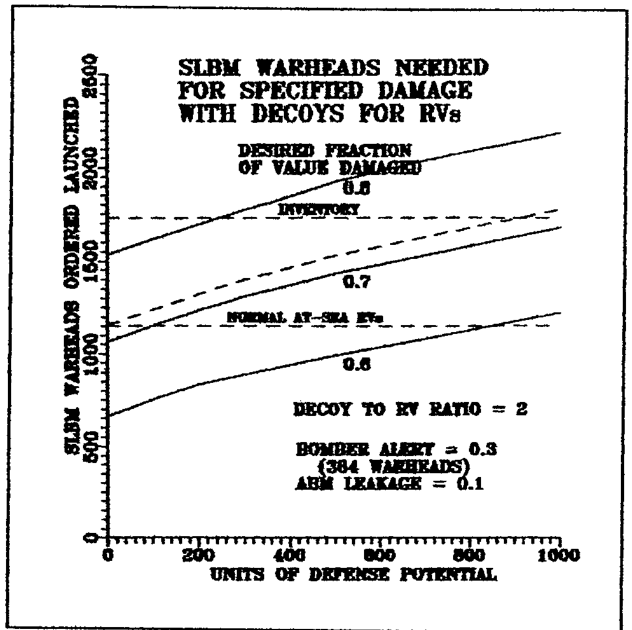

Figure 7

The main results in either figure are that the number of weapons needed to be ordered to launch to maintain a specific fraction of damage grows much less rapidly as the defense potential increases, as compared to results presented when no decoys were employed. The reader is cautioned that these results are based on the assumption that decoys are perfect. If the missile defenses are used to attack RVs during exoatmospheric phase of flight, then many would argue that certain types of decoys could approach accurate replication of RVs. Currently, the U.S. is in the process of developing a Theater High Altitude Area Defense system (THAAD) with this purpose in mind. If the Russians were to develop an area defense that would attack RVs in the exoatmospheric phase of flight, then decoys would be light in weight and technology might permit accurate replication. The discrimination of RVs and decoys would still be important, and we turn next to this topic.

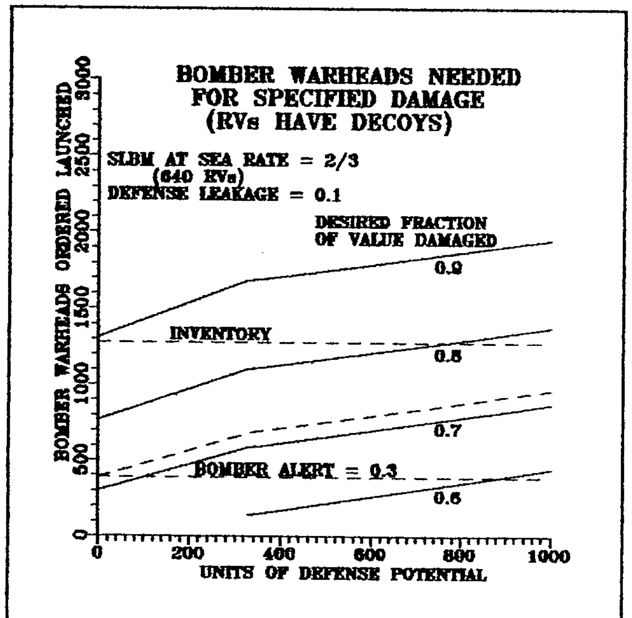

Figure 8

V - EFFECT OF IMPERFECT DECOYS

This chapter is aimed at examining the middle ground between the bounds of perfect discrimination and no discrimination between RVs and decoys. One method of analyzing this middle ground was presented in an earlier chapter. This discussion will provide an analysis of a particular example -- providing discrimination during the exoatmospheric flight regime of RVs and decoys using sensors which measure the rate of decay of temperature as a function of time. The RVs are assumed to be housed in lightweight balloons, and the decoys consist of the same types of balloons. In some cases, the balloons may contain heaters that replicate the temperature decay of the balloons containing RVs. Other discrimination characteristics may also be of interest. While not considered here, we believe that the methods to be illustrated are general enough in nature to have a broad application to other kinds of discriminants.

Analysis Approach

Sorting out which objects are decoys and which are RVs involves finding the differences between the two classes of interest. These differences may be described as the distribution densities between the two classes of objects, and they may overlap. If the rate of temperature decay is different, then the time constants would, on average, be different. Balloons without RVs inside would loose their heat rapidly, and the temperature would decrease more quickly than balloons with RVs inside them. The decoys (empty balloons) would have a time constant of temperature decay that would be smaller than the RVs, and this difference could be detected by some sort of sensor operating at some distance from the objects. Not all of the decoys would loose heat at the same rate, nor would the RVs. For each class there would be some mean rate of temperature decay, with some variation about this mean. Thus, the distributions for each class could be described statistically in terms of a mean and a standard deviation for each class of objects. Here, it will be assumed that the temperature decay rates follow a normal distribution. The density distribution for the RVs would be given by

$$(9)\quad f(R) = K*\exp\{-0.5*[(x-MR)/SR]^2\}$$

and for the decoys would be given by

$$(10)\quad f(D) = K*\exp\{-0.5*[(x-MD)/SD]^2\}$$

where the standard deviations are SR (RVs) and SD (decoys), and the means of the distributions are MR (RVs) and MD (decoys). The constant K is simply the reciprocal of the square root of 2*PI.

The above formulation can be applied to the example of midcourse discrimination between empty balloons and balloons with RVs inside. Figure 9 shows the probability density functions as a function of a <u>relative</u> temperature decay time constant. In this example it is assumed that the temperature decay time constant for the decoys is one half of that of the RVs, and that the standard deviations are 0.3. Two vertical lines, A and B, indicate some possible threshhold values for discrimination. In general the probability that an RV is perceived as a decoy is given by

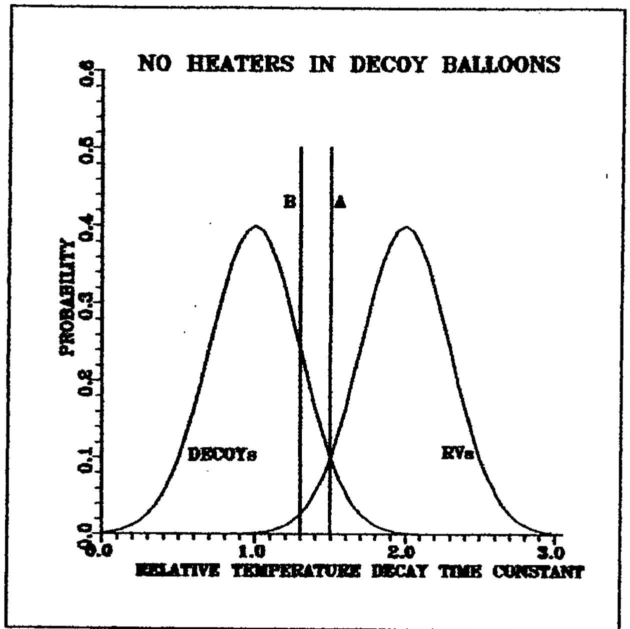

Figure 9

$$(11)\quad P(RV \text{ ---> } decoy) = \int_{-\infty}^{B} f(R)*dx = f$$

and the probability that a decoy is perceived as an RV is given by

$$(12)\quad P(decoy \text{ ---> } RV) = \int_{B}^{\infty} f(D)*dx = g$$

In some cases, the discrimination threshhold B might be set equal to A (where the two density functions intersect), and the two probabilities would be equal even though the standard deviations of the two distributions may be different. The author has labeled the value of the two probabilities when equal as the "confusion factor" i.e. f = g.

<u>Example of Imperfect Decoys</u>

Where should the discrimination threshhold be set? In this example, the two means of distributions are separated by 3 1/3 standard deviations (SR = SD = 0.3), and discrimination would seem to be straight forward. However, the optimal setting would depend on the size of the attack, the defense potential, leakage, and the separation between the two classes in terms the discrimant being employed by the defense. To be more specific,

we assume that the attack is the same as the one examined earlier. Under this assumption there would be 986 RVs and 1972 decoys arriving at the missile defense perimeter. The leakage of the defense is 0.1, and the defense potential will be varied over a broad range of values.

To determine where the discrimination threshhold should be set, we assume that the defense would want to minimize the fraction of value damaged by the attacker or retaliator. Figure 10 shows the fraction of value damaged as a function of where the threshhold should be set (along the x-axis). Where the defense potential is some fraction of the number of attacking RVs (250 to 500 units), the optimal placement of the threshhold value is biased toward the mean of the RV distribution. The defense should make sure that any of its scarce resources are used to counter RVs, not decoys. As the level of defense potential approaches the number of RVs (about 1000), then the threshhold needs to be set about half way between the means of the distribution. Under these conditions, the confusion factor is 0.048, or very low because the means of the density functions are far apart. In this example, the change in outcomes of the attack is significant as a function of the threshhold placement because the two distributions are well separated. This separation is large because we have assumed that the decoys are not equipped with heaters that might be used to replicate the temperature variations of RVs with time.

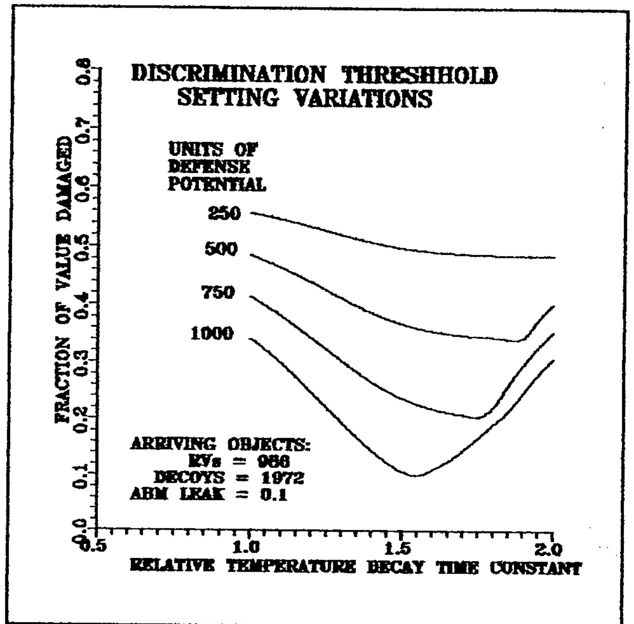

Figure 10

Example of More Nearly Perfect Decoys

The decoys used by the retaliator could be improved to more nearly replicate the appearance of the RVs. One step to achieve this goal would be to install heaters in the decoy balloons. In this analysis we assume that the decoy heaters do not quite replicate the RVs in terms of temperature decay. The separation between the means has been decreased from 3.333 to 1.00 standard deviation (means at 1.7 and 2.0, standard deviations of 0.3). With these changed conditions, there is considerable overlap between the two distributions as shown in Figure 11. If the discrimination threshhold were set at the intersection of the two

distributions, then the confusion factor would be 0.3085, i.e., the probability that the RVs would be perceived to be decoys and vice versa. If the confusion factor were to equal 0.5 (or the sum of the two perception probabilities equal to 1.0), then the defense could not tell the difference between decoys and RVs. In this circumstance, the best condition for the attacker, the decoys would be perfect. Under the present assumptions, the decoys are not perfect, but there is a substantial amount of confusion on the part of the defender. His allocation of defenses would follow the algorithm derived in an earlier chapter of this report.

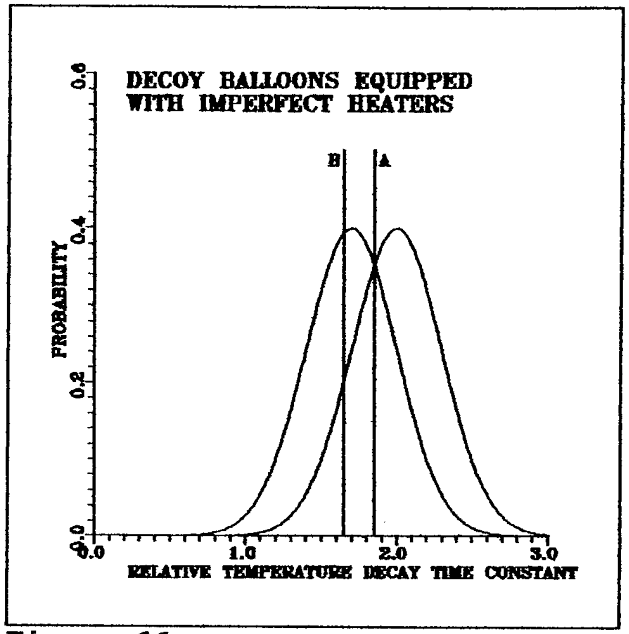

Figure 11

When the means of the two distributions are closer (one standard deviation apart), how should the defender set his discrimination threshhold? Again, this situation is analyzed by examining how the damage inflicted by the attacker varies as a function of the threshhold value setting. Figure 12 shows these results. The defender would want to minimize the fraction of value damaged. When the defense potential is small compared to the number of attacking RVs, the setting is biased toward the mean of the RV distribution. For larger values of defense potential, the minimum point shifts toward the mean of the decoy distribution. An important property of the curves depicting attack outcomes is that they are nearly constant as a function of the setting of the discrimination threshhold. In the figure, a vertical dashed line indicates a setting at the intersection of the two density

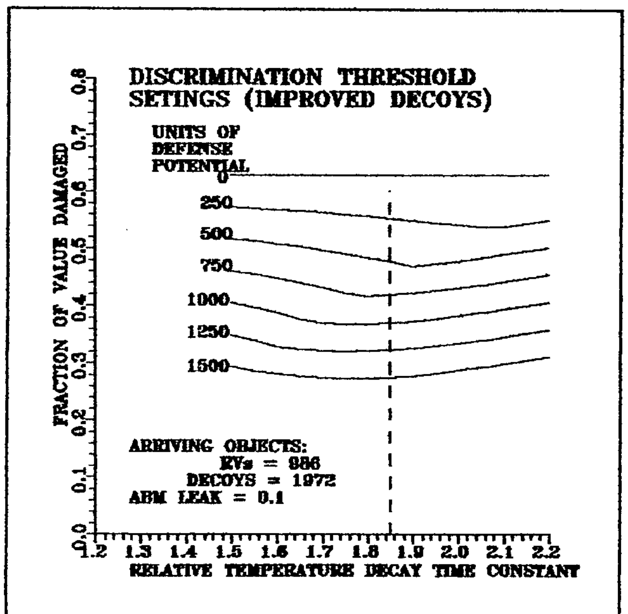

Figure 12

distributions. For this setting the probability that RVs are perceived as decoys is exactly equal to the probability that the decoys are perceived as RVs, i.e. the "confusion" is 0.3085. This setting is not far from optimum for low levels of defense potential, and is very close to optimum at high levels of defense potential. As a working rule of thumb, the discrimination threshhold should be set to the intersection of the two distributions when the overlap between the two distributions is substantial.

Based on these examples, some general trends can be noted. If the attacker can build decoys to approximately replicate RVs by installing heaters in the decoy balloons, then more damage will be inflicted on the valued assets of the defender. Under the assumptions used in these analyses, RVs and decoys without heaters could be classified fairly easily, based on the discriminant chosen here. This situation changes if heaters, even imperfect ones, were to be installed in the decoy balloons. If the misisle defense consisted of 1000 units of defense potential with a leakage of 0.1, then the fraction of damage to value would be about 0.1 when decoys had no heaters. With imperfect heaters installed in the balloons, the fraction of value damaged would be about 0.37. With perfect decoys, the fraction of value damaged would be about 0.44. If the attacker could superimpose the decoy density distribution over that of the RVs, then the decoys would be considered perfect, confusion would abound, and the defender's best allocation of resources would be to shoot at all objects uniformly.

The attacker could employ yet another tactic besides trying to move the means of the two distributions toward each other. The standard deviation of both distributions could be increased thus increasing the amount of overlap. This property could be implemented by installing different types of heaters on each decoy, and installing a variety of heaters on the RVs. Such a tactic is often termed "anti-simulation" and would increase the degree of defender confusion. Under these conditions, the defense might start examining some other form of discriminant, such as signatures in the visible light spectrum, or radar signatures. The analysis indicated here could be extended to other discriminants, and is not limited to the decay of temperature that was addressed in this particular analysis.

Second Strike Effectiveness With Imperfect Decoys

In this discussion the focus is on defining the possible second strike outcomes between having perfect decoys for RVs and using low credibility decoys for RVs in retaliation. First, the confusion factor will be quantified, and then, it will be employed to show retaliation outcomes for two different force postures, with and without bomber operations. The effectiveness of the second strikes will be estimated in terms of the fraction of valued assets damaged.

The confusion factor corresponds to a special setting of the threshhold for discriminating between RVs and decoys. When the density functions of the two objects intersect between the means of the two distributions, then the probabilities that decoys are perceived as RVs and RVs are perceived as decoys are equal. Either of these probabilities is called the "confusion factor." Setting the threshhold in this manner leads to a quantification of the confusion factor. Figure 13 shows the relationship between the confusion factor and the separation of the two means of the density functions of RVs and decoys in terms of the number of standard deviations separating them. When the abscissa is zero, then the decoys are perfect. The larger the value of the separation of the means, then the more imperfect are the decoys. When the separation is four standard deviations, there is very little confusion, and a very high level of discrimination should be possible. These comments are conditional on the assumption that the missile defender knows when he is confused, and to what extent.

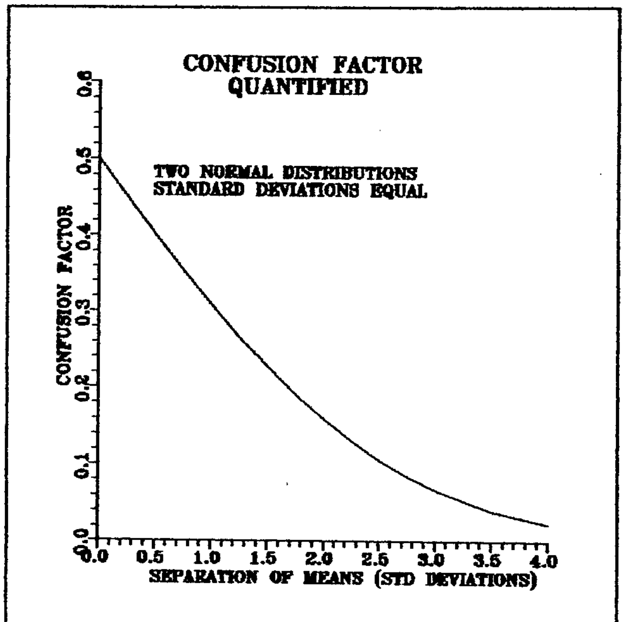

Figure 13

What would be the effectiveness of a retaliation consisting only of ballistic missile RVs in the presence of a robust missile defense for a variety of decoy credibilities? Figure 14 indicates the results ranging between 0 and 1000 units of defense potential (leakage = 0.1) and the separation of density distribution means from 0 to 4.0 standard deviations. When bombers are not on alert, as indicated in this figure, the degree of discrimination seems vitally important. The outcomes between perfect decoys and almost imperfect decoys (x = 4) is very

different for a defense potential of 1000 units. These outcomes reflect the policy of having no bombers on strip alert on a day-to-day basis. So long as the geopolitical relationships between the United States and Russia seem conciliatory, then outcomes such as those illustrated may seem to be quite improbable. In a crisis, or if Russian leadership changes in a hostile way, the attitude of the U.S. leadership might change bomber alert rates.

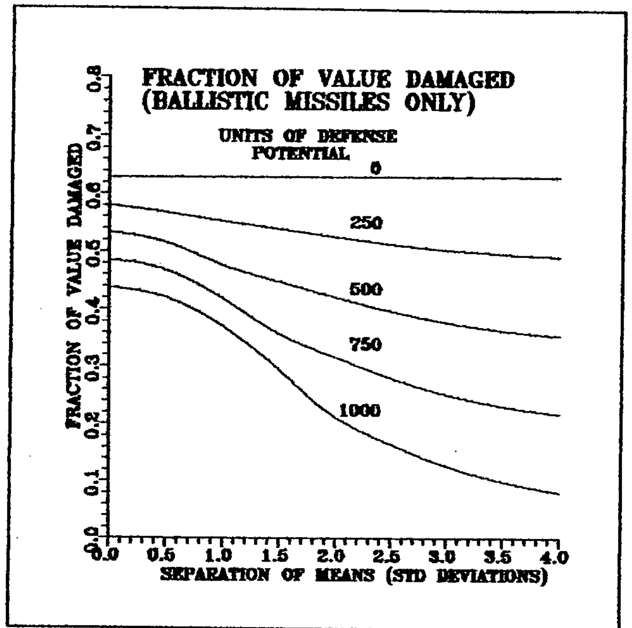

Figure 14

If the National Command Authority were to decide to put bombers on strip alert, then the effectiveness of a retalitory strike would change. Under these new conditions, bombers might be put under an alert rate of about 30%. With this assumption, the effectiveness of a retaliation is illustrated in Figure 15 as a function of the loss of credibility of the decoys accompanying ballistic missile RVs. With imperfect decoys the retaliatory effectiveness would degrade, but not nearly so much as if bombers were not on alert. In this analysis bombers would evade missile defenses and would be assigned to attack high value targets whenever their penetration probability exceeded that of the ballistic missile RVs. The addition of alert bombers would improve the effectivenss of the retaliatory blow. One cannot escape the conclusion that bombers will have, and will continue to have a vital part to play in a retaliation should the Russians decide to strike first. The degree to which the U.S. can develop nearly perfect decoys for their RVs is important, but the alert level of the bombers

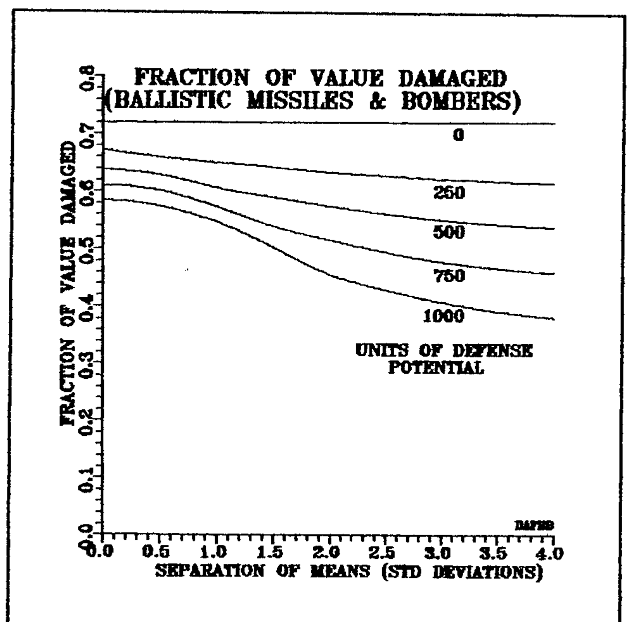

Figure 15

also plays a crucial part in the effectiveness of a second strike.

VI - ASPECTS OF FIRST STRIKE STABILITY

The purpose of this chapter is to examine first strike stability between the U.S. and the former Soviet Union (FSU). The index of first strike stability is a two-sided index which is but one factor in a larger arena -- crisis stability. First, a short review of the index is presented. Then, the results of computations based on earlier assumptions will be illustrated.

The index of first strike stability is the product of two ratios. The first is the ratio of the cost to the U.S. of striking the FSU first to the cost of waiting for the FSU to strike first. The second ratio is similar -- the cost to the FSU in striking first divided by the cost of the FSU waiting for the U.S. to strike first. The original formulation of this measure was developed by Kent and Thaler [4]. In this report, we will depart somewhat from their formulation.

$$(13)\quad \text{FSS index} = \frac{C(\text{US FIRST})*C(\text{FSU FIRST})}{C(\text{US WAITS})*C(\text{FSU WAITS})}$$

The "cost" in this equation is a combination of two factors. First is a function of the damage inflicted on a defender. The second factor is a function of the damage not done to the first striker by the defender. Thus, the costs are given by

$$(14)\quad C(FSU) = D(FSU)^{0.75} + 0.3*[1 - D(US)^{0.75}]$$

$$(15)\quad C(US) = D(US)^{0.75} + 0.3*[1 - D(FSU)^{0.75}]$$

where the damage to the U.S. and the FSU is indicated by the terms D(US) and D(FSU). In the present formulation, the damage function is the Pareto distribution of valued assets described earlier.

$$(16)\quad D(US) = VR_{FSU} + VB_{FSU}$$

$$(17)\quad D(FSU) = VR_{US} + VB_{US}$$

where the damage to U.S. assets is the sum of damage inflicted by re-entry vehicles and bombers sent by the FSU, and the damage suffered by the FSU is the sum of the damage inflicted by re-entry vehicles and bombers sent by the U.S. The function describing the fraction of valued assets damaged was given in Chapter II (see equations 3, 4, and 5, and accompanying discussion).

First strike stability is a function of force structures, the postures of the forces, the extent and quality of defenses,

and whether or not decoys accompany the retaliating RVs. The force structures and postures were enumerated earlier. The structures assumed were those compliant with the START II Treaty. The postures were dependent on whether or not some of the forces were on alert. For posture A, all alert warheads are assumed to be on ballistic missiles. For posture B, about 30% of the bombers would be on strip alert. Alert bombers are assumed to escape the effects of an attack, while non-alert bombers and SLBMs in port are assumed to be destroyed.

In this analysis, the index of first strike stability is shown as a function of the extent of missile defenses deployed in the U.S. and the FSU. It is assumed that both sides deploy missile defense in equal amounts, and the extent of these defenses range between zero and 1000 units of defense potential. The missile defense leakage is assumed to be 0.1 for both sides. Figure 16 shows the results. Bombers, when employed by both sides, would have a combined probability of escaping the attack and penetrating air defenses of 0.8. The dashed curves indicate the results when either no decoys are employed or when decoy discrimination is perfect. Under these conditions the first strike stability decreases as a function of increasing missile defenses. For the condition where only ICBM and SLBM warheads are used in a second strike (Posture A), the first strike stability is quite low when the defense potential is about 500 units or greater. When bombers are sent in a second strike, the first strike stability decreases with increasing larger ballistic missile defenses, but at a much slower rate. The employment of bombers substantially raises the first strike stability, in part because they are assigned to the higher value targets when their probability of arriving at their aimpoints is greater than that of the ballistic missiles.

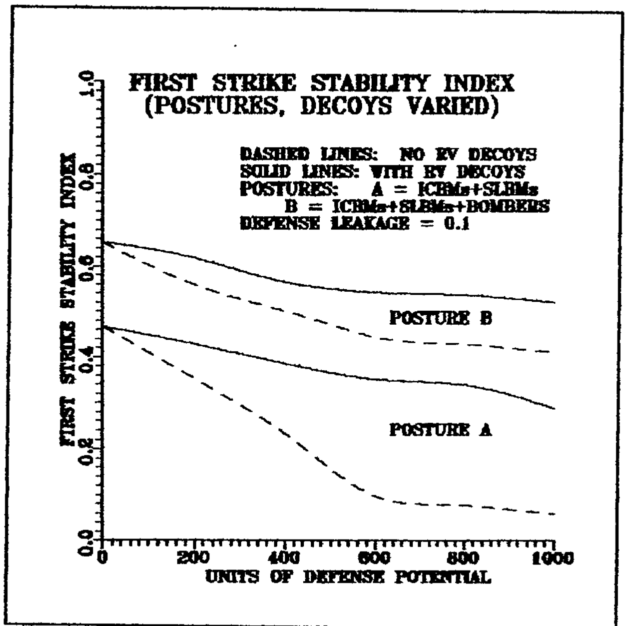

Figure 16

When decoys are perfect, then the results are indicated by the solid lines. In this analysis, it was assumed that there would be twice as many decoys as RVs (RVs = 986, decoys = 1972). Under these conditions, first strike stability decreases much more modestly compared to when decoys were not used or were not credible.

First strike stability is sensitive to the leakage rate of the theater missile defenses. If the theater missile defense were less robust, the outcomes would be different than illustrated in the above example. To illustrate this effect, we assume that the defense potential would be 1000 units. Figure 17 shows the first strike stability as a function of missile defense leakage. The other parameter of importance is the ratio of decoys to RVs. This parameter is varied between zero and three. The increase in this ratio does increase the first strike stability index, up to a point. When the ratio achieves a value of three, the first strike stability index is nearly insensitive to defense leakage rate. In the previous analyses, the ratio was set to two decoys for each RV. Under these conditions some benefit is realized by increased values of leakage rate of the missile defenses. When there are no decoys, or a ratio of one decoy for each RV, then increases in leakage rate have a pronounced effect on first strike stability.

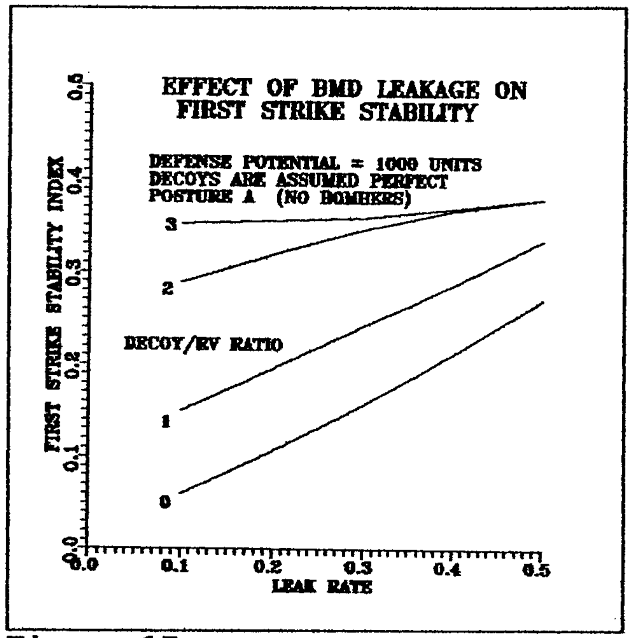

Figure 17

VII - FINDINGS AND OBSERVATIONS

The purpose of this report was to examine the effects of theater missile defenses if it were active in a strategic exchange. The analyses were directed at the effectiveness of a U.S. retaliation with and without decoys replicating ballistic missile re-entry vehicles (RVs), decoy and RV discrimination, and first strike stability. Various methods of analysis for addressing these issues were described. First, we offer our findings, and then discuss some of the background behind these findings.

In examining the effectiveness of a U.S. retaliation, our findings address the role of exoatmospheric decoys for countering high altitude ballistic misisile defenses. The second strikes analyzed consisted of retaliation by RVs alone (Posture A) and by a mixed force of bombers and ballistic missiles (Posture B) facing a robust theater missile defense system.

Against this backdrop, decoys provide leverage to the second striker in a number of ways. Decoys can alleviate the loss of retaliation effectiveness. The fraction of Russian assets damaged decreased dramatically when no decoys were used in the face of increasing defenses. In an effort to maintain damage levels, more bombers could be put on strip alert or more SLBMs could be put to sea. Neither of these measures were effective at high levels of defense. The number of bombers or SLBMs sometimes exceeded the future projected inventory of these weapons in the U.S. arsenal. With decoys, these measures provided viable solutions for maintaining retaliation effectiveness if the Russians were to deploy a robust TMD. Less than perfect decoys still provided these advantages but to a somewhat lesser degree.

First strike stability is considerably improved if <u>both sides</u> employ decoys in a first or second strike. In an offense dominant strategic environment, the introduction of ballistic missile defenses degrades first strike stability. Decoys decrease the effectiveness of missile defenses. Thus, decoys lessen the degradation of first strike stability, particularly when bombers are not a part of either first or second strike.

Retaliatory strikes carried out by a mixed force of bombers and ballistic missiles are more effective than second strikes carried out by ballistic missiles alone. Without missile defenses, the bombers supply an increased level of weaponry. If TMD were deployed in Russia, the bombers would avoid this threat and could be assigned to strike higher valued aimpoints. When decoys accompany the RVs, retaliatory strikes involving mixed forces are even more effective. Thus, bombers will play an important role in making retaliation effective. In addition, a mixed force on <u>both sides</u> provides for an improved index of first strike stability, especially when decoys are used to decrease the effectiveness of ballistic missile defenses.

The numerical results behind these findings must not be considered as absolute. Uncertainties may cause the numerical results to change. The results of these analyses should be sufficient to capture trends and relative improvements even when there are uncertainties. The assumptions used as inputs for the analyses in this report do contain many uncertainties. Where uncertainty was a major factor, assumed values of various parameters were varied to better understand their importance and effects on results. The major assumptions used here included estimates of force structures, their postures, and the extent and capabilitys of theater missile defenses. The force structures were based on projections provided by the author in consultation with others. These projections met the terms of the START II Treaty. Shortly after the bulk of the analysis was complete the Department of Defense presented the results of the Nuclear Posture Review (NPR)[5]. The findings of the NPR with regard to

strategic nuclear forces are summarized in the Appendix and are compared with assumptions used in this report.

The model describing ballistic missile defense was kept simple because the Russians have not built a theater missile defense system, and it is difficult to know of its details. The extent of a new Russian homeland defense employing technology developed from a TMD was varied over a large range of values. The leakage rate assumed (0.1) was chosen to represent a worst case. The credibility of decoys in the presence of TMD was varied between the upper bound of perfect replication of RVs and the lower bound where decoys were either not employed or were considered to be totally ineffective. The random subtractive defense model currently provides the best estimator of a future TMD that is available at this time.

The problem of discriminating between RVs and decoys was described in this report by examining an example -- a discriminant based on temperature decay of RVs and decoys. Other discriminants could also be analyzed employing the same methodology. The generality of the method would seem to be applicable if the defense system were to try to discriminate the objects on the basis of signatures in other spectra, such as radar or visible optical spectra. Discrimination in multiple spectra, while possible from a technical point of view, may be out of bounds in the development of a <u>theater</u> missile defense system on the grounds that it would be very expensive and beyond the amounts budgeted for a project intended to protect allies and friendly forces from attacks by short range and unsophisticated ballistic missiles in the third world.

Discrimination between RVs and decoys can be made more difficult by utilizing anti-simulation. This objective can be achieved by making all objects detected by the missile defense different, or by spreading the density distribution functions so as to create a considerable amount of overlap. The methodology presented in this report was limited to discrimination between two object classes, but has been extended to three object classes [6]. The classes might be decoys, RVs, and debris. This problem was encountered by Patriot batteries deployed during the Persian Gulf War. In the future, U.S. theater missile defenses may face a high degree of confusion in confrontations with more sophisticated opponents than is currently the situation.

Finally, one arms control issue related to theater missile defenses is offered. If both the U.S. and the Russians were to agree that theater missile defense systems were to be deployed <u>only outside their homelands</u>, then this analysis would not have needed to focus on strategic retaliation and its effectiveness. We suggest that "theater missile defenses" should be deployed only in <u>theaters of operation outside the homeland</u>.

APPENDIX

In September, 1994, the Department of Defense completed and briefed the results of the Nuclear Posture Review (NPR). The purpose of this appendix is to summarize the NPR results with regard to strategic nuclear forces and compare them to the assumptions of the present analysis. The following table presents the NPR force structure on the left, and the force structure assumed for this analysis on the right.

Table 1A - Force Structures

Weapon Type	Weapon Platform	Nuclear Posture Review Warheads	Analysis Assumptions Warheads
ICBM	Minuteman	400/500	500
SLBM	Trident D-5	1680	1728
Bomber	B-52	1000	952
	B-2	320	320
TOTALS		3400/3500	3500

The differences between NPR and this set of analyses is not great. The number of warheads carried on each D-5 SLBM is assumed to be 5, and the total warheads are 48 less than was assumed in this study. The NPR indicated that the B-52 fleet would consist of 66 bombers. Under this reduction 40 B-52s could carry 12 air launched cruise missiles (ALCMs) each, and 26 could carry 20 ALCMs each, and still remain within the terms of the START II Treaty. The decrease in SLBM warheads could be offset by an increase in bomber warheads. Under the assumptions of this analysis the number of RVs arriving at the perimeter of a Russian TMD would be 928 instead of 986. This decrease would be due to the reduced number of RVs on SLBMs and the decreased number of submarines at sea. The 928 RVs assumes that 80 Minuteman ICBMs would survive a first strike, and that 9 submarines would be at sea with 120 RVs each. Both the SLBMs and ICBMs were assumed to have a combined availability and reliability of 0.8. The number of alert bomber weapons would increase from 384 to 400, assuming a 30% strip alert rate. The total number of nuclear weapons is the same for either set of assumptions. The number of ballistic missile RVs has decreased by about 2% in the total count. The number of ballistic missile RVs surviving a first strike would be 1160 rather than 1232, a decrease of about 6%. These differences would not significantly change the trends and finding of the analyses contained in this report.

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